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24 June 1960

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Commander
Air Force Cambridge Research Center
Laurence G. Hanscom Field
Bedford, Massachusetts

Attention: John N. Howard, CRZCI
             Geophysics Research Directorate

Subject: Progress on Contract No. AF 19(604)-5877
           "Research on Atmospheric Attenuation of Infrared Radiation"
           LAS Task E173

Dear Sir:

        This is an informal progress report covering the work conducted during May 1960 under the subject contract. During the early portion of the reporting period, fog measurement data obtained at Arcata, California was reduced and a preliminary report was submitted. Additional spectra are presently being reduced in an attempt to extract all possible useful data. The results will be incorporated in a report which will be presented at the AMRAC*/ Symposium in Seattle, Washington on 21 July 1960.

        Calibrations were made at Cape Canaveral, Florida using a Cambridge Research Center blackbody operated at $1000^{\circ}C$ at a distance of 200 feet from the collecting mirror of the system. Equipment response values are given in Table 1. The spectral irradiance at the collector, which constitutes a signal equal to noise for a bandwidth of 0.1μ, is given as $H_{\lambda 0.1}$.

        During the measurements conducted at Cape Canaveral, the graphite emitters exhibited nonuniformity and were considered to be unusable. However, with approval from Cambridge Research Center, LAS proposes an

*/ Antimissile Research Advisory Council.

LAS-L-E173-7

Table 1

Response of Ground-Based Spectroradiometric Equipment

Wavelength, λ (micron)	Spectral Irradiance, $H_{\lambda 0.1}$ (watts/cm^2/0.1μ $\Delta\lambda$)
2.99	5.9×10^{-12}
2.93	4.7×10^{-12}
2.91	4.6×10^{-12}
2.39	7×10^{-13}
2.34	6.8×10^{-13}
2.28	7.0×10^{-13}
2.2	7.0×10^{-13}
1.53	7.2×10^{-13}

experimental study using five emitters to assess the severity and reproducibility of the gradients across the emitters and therefore assess the possibility of using the emitters for conducting the originally scheduled measurements of atmospheric transmission from tethered balloons. The presence of gradients in themselves do not prohibit measurements. The important factor is the uniformity of such gradients from source to source. The presence of the gradients increases the complexity of assessments but does not make it impossible.

LAS, therefore, proposes to undertake a photographic comparison of five emitters. Photographs of the emitters are to be made with accurately controlled exposure intervals during burning and cooling. A red filter (Wratten F) is to be used over the lens to give a photographic response of approximately that of the optical pyrometer. Calibration will be achieved by photographing ribbon filament lamps whose temperatures are set by an optical pyrometer. A microdensitometer (scanning type) is to be used to measure the films. In order to cover as wide a temperature range as possible (1400° to 900°C) a long-scale panchromatic film is required. Such a film has an exposure range (in the linear portion of the H and D curve) of 100 to 200 to 1. If one assumes a gamma of unity and a densitometer capable of

measuring to $+0.01$ density unit over the range of 2 to 2.3 density units, the error of determining the temperature ($1400°$ to $900°C$) is approximately $+10°C$. This appears to be ample accuracy for studying the emitter temperature contours and their reproducibility.

LAS believes that this one final set of tests on the Thermit emitters is warranted before totally discarding this form of standard source.

Alternative methods to carry out the atmospheric attenuation measurements are under consideration. Three systems are discussed below.

1. <u>Collimated source to be carried in aircraft.</u> A collimated source consisting of an arc or Nernst glower is carried in an airplane and manually pointed at the ground station while flying in a circular, constant-elevation path about the ground station. To reduce the required accuracy of pointing, a relatively short focal-length collimator would be used. The system is optically feasible, but the problem to be studied is the method of instrumenting the airplane. This will be given further consideration.

2. <u>Diffuse reflectors on balloon or aircraft with the source on the ground near a receiving station.</u> A source with collimator is located on the ground near the receiving station and an airplane or balloon is equipped with a light-diffusing area. Receiving optics would image the diffuse area upon the slit of the monochromator. Preliminary calculations on this system using a large (60 inches) searchlight and large diffusing area (9 feet in diameter, maximum for a 30,000-ft path) indicate that the system is not feasible. The calculations show that the received flux is down by a factor of 30 from that flux required to achieve a signal equal to noise.

3. <u>Retrodirective reflectors carried by balloons or aircraft, the source being an integral part of the receiving station.</u> In this proposed system the receiving station is altered so that the collimator is used for both the source collimator and receiving collimator. Retrodirective reflectors are used on an airplane or balloon for returning the energy to the receiving collimator. Computations were made on a system employing a 12-inch diameter, f/5 mirror for both the transmitting collector and receiving collector, and a $3700°K$ arc. Transmitted and received beams are separated by a beam splitter. Results indicate that a $0.58\text{-}cm^2$ area of retrodirective reflector would result in a signal to noise of unity at 2.2μ for a range of 30,000 feet. The calculation is included for reference (see Appendix A).

In the windows of the spectrum where transmission is high, a high signal-to-noise ratio can be achieved from fairly small areas of corner cube. For instance, a corner cube array of 1200 cm^2 gives a signal-to-noise ratio of about 2000. It should be observed that the transmission factor for the double path appears as the square of the transmission for the 30, 000-foot single path.[*] This, in effect, narrows the usable spectral regions for a given signal-to-noise ratio calibrated in a region of high transmission.

An advantage of the system is the possibility of chopping either at the source, or at the retrodirective reflector. By chopping at the source all background effects will be eliminated except for the energy backscattered from the projected beam. If the chopping is at the retrodirective reflector the backscattering is likewise eliminated, but the background produced by the atmosphere within the volume of the path from the source to the reflector is retained.

In such a retrodirective system, it appears that an airplane has distinct advantages over a balloon as a vehicle, e. g. :

1. Control of the transmission path, i. e., the airplane can fly in a circle around the ground station and be carefully monitored and controlled.

2. Chopping could be done at the retrodirective reflector, thus gaining the advantage outlined above.

3. A plane array could be used. The balloon would require a spherical array and hence need 3-1/2 times as much total area of retrodirective reflector (projected area would be the same). This factor is important only in that the reflectors may be quite expensive.

In view of the results of this preliminary study we will investigate the possibility of obtaining suitable retrodirective reflectors.

A program for radiometric measurement of the sun is being studied. This requires considerable modification of the present system in order that the solar image is completely contained within the slit of the monochromator. In order to obtain higher spectral resolution it is desirable to convert the system to a double-pass instrument for which the components exist in our laboratories. The use of a bolometer is also indicated.

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[*] Refer to **Research on Atmospheric Attenuation of Infrared Radiation,** Laboratories for Applied Sciences, Report No. CML-L-E173-1, p. 5, 30 June 1959. (U)

During the month of June the experimental study of the emitters will be continued and should be substantially completed by the early part of July 1960.

Respectfully submitted,
Laboratories for Applied Sciences

Howard T. Betz
Senior Research Physicist

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Appendix A

The objective of this calculation is to determine the area of a corner cube necessary to achieve a signal equal to system noise as shown in Figs. 1 and 2.

NOMENCLATURE

M	12-inch mirror
MS	12-inch mirror as a source
MC	12-inch mirror as a collector
R	corner cube (reflector)
S	arc source
SL	monochromator slit
I	image

The peculiar properties of a corner reflector are that all rays which fall on the reflector are returned to their source, displaced at most by the diameter of the corner reflector. In principle, losses caused by this displacement can be minimized by using an array of small cubes. Other losses which occur in the outlined system are caused by dead space on the system axis, imperfection in the corner cubes, scattering from dust on the half silver plate, and one-half losses on the half silver plate itself. This last item is dealt with by introducing a factor of 1/4, since all usable energy encounters the half silver plate twice. The other losses can be expressed as

$$(1 - z_1)(1 - z_2) \ldots (1 - z_n) , \tag{1}$$

in which z_n represents the percentage loss at each point which is small. All second-order terms can be neglected, and so

$$(1 - \sum_n z_n) . \tag{2}$$

Corner Cube Array

30,000 ft

Ω

Source, S

θ

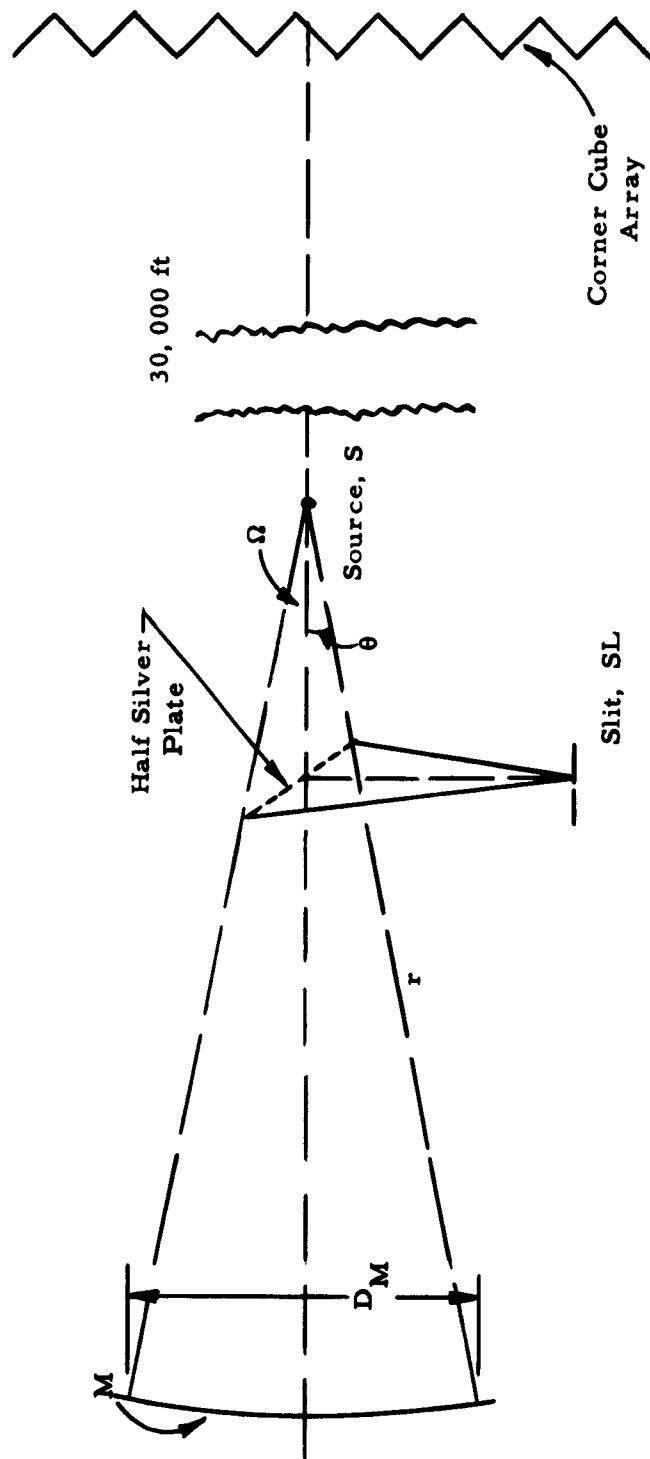Half Silver Plate

Slit, SL

r

D_M

M

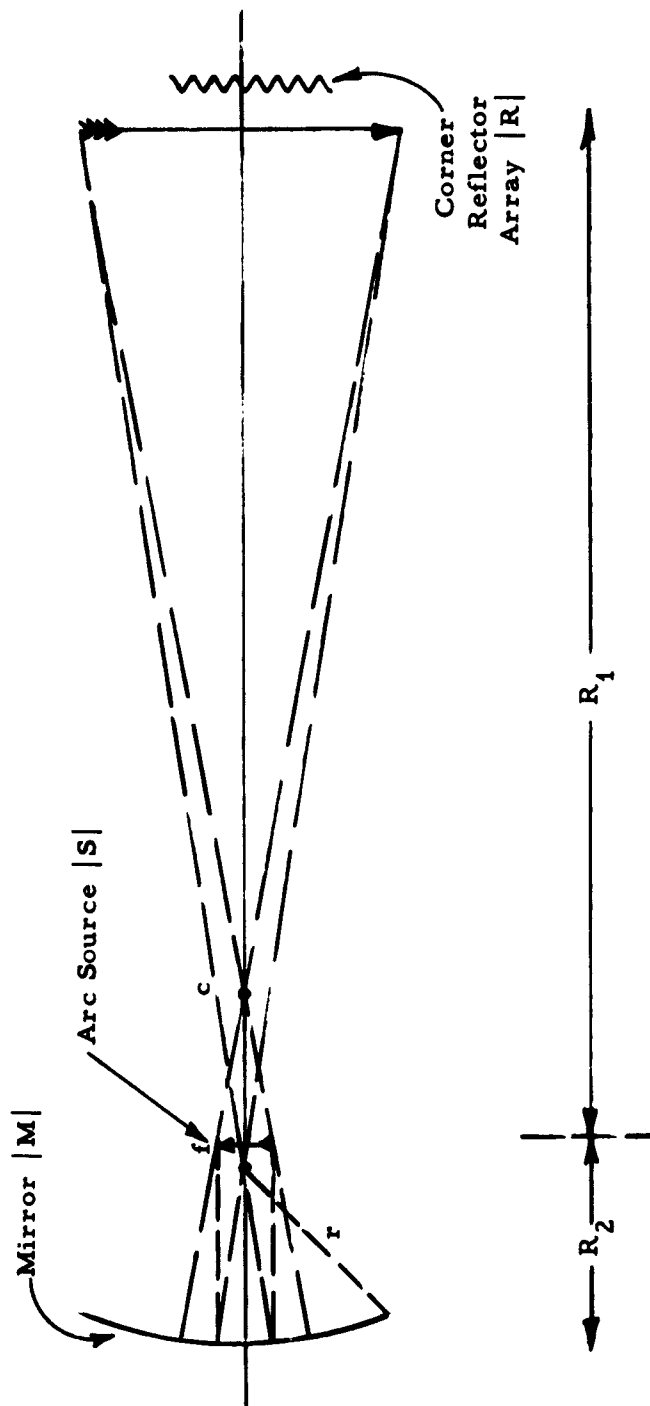Figure A-1. Diagram of transmitting and receiving optics.

Figure A-2. Diagram illustrating image and corner reflector size relationship.

The summation of z_n is probably less that 20% for all of the system outside the monochromator itself.

Assuming then that there are no loss factors,

$$P_{\lambda_{SL}} = P_{\lambda_{MC}} = P_{\lambda_R} \quad , \tag{3}$$

expressing the fact that all energy at the reflector is returned to the mirror and subsequently focused at the slit.

The power received by the corner reflector is

$$P_{\lambda_R} = (A_R / A_{IR}) \, P_{\lambda_{MS}} \quad , \tag{4}$$

in which

$P_{\lambda_{MS}}$ = the total power received by the mirror from the source

A_R = area of the reflector (corner cube array)

A_{IR} = area of the image projected by the source at the reflector.

$$A_{IR} = M^2 A_S \quad , \tag{5}$$

in which

A_S = area of arc source

M = magnification = R_2 / R_1

R_2 = 30,000 ft; R_1 = 5 ft

$M^2 = (3/5 \times 10^4)$.

$$P_{\lambda_{MS}} = A_S \int J_{\lambda_S} \, d\Omega \quad , \tag{6}$$

in which

$$J_{\lambda_S} = (W_{\lambda_S} / \pi) \cos \theta$$

$$d\Omega = 2\pi\theta \, d\theta \quad .$$

But for an f/5 system,

$$J_{\lambda_S} \cong \text{constant}$$

$$\Omega \cong A_M/r^2 \cong A_M/R_2^2 = \int d\Omega \cong 2\pi\theta^2/2$$

$$\cos\theta \cong 1.$$

$$P_{\lambda_{MS}} = A_S W_{\lambda_S} \theta^2 \; ; \tag{7}$$

$$P_{\lambda_{SL}} = A_R/M^2 \times W_{\lambda_S} \theta^2 \; ; \tag{8}$$

$$\theta \cong 0.1$$
$$\theta^2 \cong 0.01$$
$$M^2 = 25/9 \times 10^8 \; .$$

Now define

$$H_{eff} = P_{\lambda_{SL}}/A_M \; ,$$

to compare to the previously established calibration on the monochromator; $A_M = 585 \text{ cm}^2$.

$$A_R = \frac{H_{eff} A_M M^2}{W_{\lambda_S} \theta^2} \tag{9}$$

Reintroducing the losses,

$$P_{\lambda_{SL}} = (1 - \sum_n z_n)\left[\frac{1}{4}\right]\left[T(A)_\lambda\right]^2 \left(\frac{A_R}{M^2} W_{\lambda_S} \theta^2\right) \; , \tag{10}$$

in which $T(A)_\lambda$ is the spectral transmission of the atmosphere at 30,000 ft.

$$A_R = \frac{H_{eff} \, A_M \, M^2}{W_{\lambda_S} \, \theta^2 \, (1 - \sum_n z_n) \left[\frac{1}{4}\right] \left[T(A)_\lambda\right]^2} \qquad (11)$$

For a signal equal to noise at 2.2μ, $3700^\circ K$, 0.1μ bandwidth,

$$H_{\lambda eff} = 0.7 \times 10^{-12} \, (watt/cm^2 \times cm_{\Delta\lambda}^{-5})$$

$$W_{\lambda_S} = (0.9 \times 10^2)(1.66 \times 10^{-1})$$

$$T(A)_\lambda^{\ 2} \cong 0.96 \qquad\qquad (1 - \sum z_n) \cong 0.8$$

$$A_R = \frac{(0.7 \times 10^{-12}) \times (585) \times (9) \times (4)}{(0.9 \times 10^2 \times 1.66 \times 10^{-1}) \times 25 \times 10^{-8} \times 10^{-2} \times 0.8 \times 0.96}$$

$$= 0.58 \, cm^2 \ . \qquad (12)$$